

THE COLORATION OF ROCKS AND SOILS

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ROCK COLORATION

Perhaps the most colorful area of rocks and soils in the United States is that vast arid tableland known as the Colorado Plateau. This area comprises sedimentary materials which were laid down in extensive inland seas millions of years ago. Its physiography involves jumbled mesas, canyons, valleys, and lesser plateaus. Its multiplicity of color ramifications is due to a combination of a number of minerals present (particularly iron) with its arid climate. Aridity, with its predominantly oxidizing atmosphere, is strongly conducive of high coloration.

Color nomenclature here seems to vary according to the background and purpose of the viewer. Geologists and soils men see reds, browns, yellows, purples, greens, etc. Park officials and real estate operators see colors of blood and fire—of sunup, noon, and sundown. Artists and poets see magentas, beiges, ochers, siennas, etc.

Within the Colorado Plateau areas are several famous national parks which are visited annually by thousands of tourists. Of these parks Grand Canyon, together with the Painted Desert, are perhaps the most famous. All the colors of the spectrum are to be seen here. Zion Park has its Great White Throne rising 3,000 feet above its cliffs of red, and Checkerboard Mesa with its geometrically designed expanse of stone near its east entrance. There is Bryce Canyon with its fiery city of rock formations. Wayne Wonderland has its weird sculpture, including the Great Organ—a symphony of colors which is bewilderingly magnificent. Then there are the cream and yellow buttresses of Cathedral Valley and Nature's gargoyles in the grotesque Valley of the Goblins. Monument Valley, in the land of the Navajos, runs the gamut of nearly every color visible to the eye. Strangely enough, here and there is the greenery of bits of vegetation. Ponderosa pines cling tenaciously to rocky formations where there is seemingly not a cupful of soil present, and sparse growths of certain weeds and grasses exist under the

very extenuating circumstances which their environment presents to them.

Numerous elements lend themselves to the over-all picture of pigments in the above-named places. But, of all elements present, iron is the most versatile. Whereas combinations of cobalt, copper, magnesium, manganese, titanium, etc., with various anions, can produce nearly all of the colors of the visible spectrum, hematite can, *by itself*, produce fully as extensive a coloration. It is able to accomplish this by its remarkable repertoire of surface imperfections and differentiations on the crystals of this sesquioxide which are made possible both by its heredity and its environment. When iron is present in its higher oxide form, magnetite, in either dia-, or para-, or both, states its coloration proclivity is exacerbated by new tints and hues.

It is quite possible that more has been written about the colors of rocks and soils by artists, philosophers, and poets than by geologists and soil scientists. The few scientific explanations which have been made of iron coloration ascribe variation in coloration to the presence of differently hydrated oxide forms of *ferric* iron. For example, color distinction can *sometimes* be made between hematite and Goethite. The commonly accepted reason for this is that Goethite is a hydrated oxide and hematite is not. Further, it is believed by some that iron color can be distinguished between certain mineral groups such, for example, as between the large silicate groups—the amphiboles and the pyroxenes. Such distinctions in coloration identity are hazardous, if not impossible, as will become evident further on.

In nature there are many examples of coloration which are produced, mechanically, by light refraction and not by pigments. This is true for both organic and inorganic forms. The iridescence of the feathers of a dove's breast, or of a peacock's tail, is caused by the presence on those feathers of minute excrescences, or, mechanical striations. These striae act as light barriers and "interfere" with incident light as it strikes the feathers. This interference breaks the light down into its component colors in the same manner that a glass prism does. When colors thus result, mechanically, they are referred to as "interference" colors. The colors of soap bubbles, and oil films on water, are interference colors and are due to the fact that these films are quite irregular in thickness. These

irregularities cause inequalities in film density which, in turn, act as prisms and produce the rainbow colors.

When a piece of bright, shiny iron is heated to redness and cooled, the heated area is seen to be rainbow-colored. The heating produced a delicate film of iron oxide (ferric) of varying thickness and irregularity of design on the metal surface. This film interferes with light reception at the surface of the iron, acts as a prism, or prisms, and causes the metal surface to evince iridescence. The heating acted as a "super-fast" weathering agent and, if the colored film were allowed to weather further, in open contact with the atmosphere, the iron surface would assume a nature comparable to that of weathered iron in rocks and minerals out in nature. The weathered iron would assume the variable physical nature and properties of hematite and/or magnetite. Hematite, particularly, is known to occur in nearly every color of the rainbow.

Photographic evidence of the mechanism of coloration in the "weathering" of iron metal has become possible only recently (Laukonis and Coleman, 1959). Electron micrography has been improved to the extent that forms less than one micron in diameter can be clearly photographed. These workers have shown that iron oxide crystals have geometrical, mosaic-patterned, surfaces. Also, that oxide platelets and "whiskers" are common products for metals which have been oxidized at red heat. These variously-formed and arranged surface excrescences interfere with surface incident light and cause "artificial" coloration, including iridescence. The chemical formula of iron oxide made by heating metallic iron artificially is identically the same as that of the iron oxide, hematite, formed by the "weathering" of iron compounds in rocks and soils out in nature.

A very interesting side light on the multi-colored forms of hematite is related as follows: In times now past, delicate optical lenses were polished with pulverized hematite, or natural "rouge." When the supply of satisfactory, natural rouge gave out, lens polishers resorted to making their own rouge. This process now involves the complete roasting, at a high temperature, of pure ferrous sulfate. The end product of this treatment is pure ferric oxide—sesquioxide, or hematite. It is very pure, chemically, but not "physically." The color of the individual crystals, and aggregates of crystals, ranges clear across the visible spectrum producing all the colors of the

rainbow. The explanation of this phenomenon becomes apparent when the differently colored particles are observed under a high-powered microscope. Not only do the particles vary in size but they have radically different surface physiographies. Some surfaces are smooth and regular and shiny and others are rough and dull, with minute hills and valleys and jagged peaks and buttresses of varying degrees of abruptness and extent. These surface inequalities constitute light barriers which break up incident light and thus produce interference coloration with all of its rainbow hues and tints. It is thus that both natural and artificial hematite, as well as other ferruginous rocks and minerals, can occur from place to place in such a vari-colored array. The optical principles involved in this color variation are, as yet, so tenuous that it is not known just why that a certain crystal should be red, another green or black, etc.

The coloration effects thus far mentioned can be caused by hematite, alone. When hematite combines with magnetite, or with one or more other mineral elements, such as cobalt, copper, manganese, etc., new color combinations can result. However, these differ so slightly from those caused by hematite itself, that their differences are important only theoretically and, perhaps, philosophically. There are very few areas of any size in existence which are colored, predominantly, by the rarer elements. Thus, as far as producing scenes of grandeur, magnificence, and sublimeness is concerned, the rarer coloring agents are substantially insignificant except in very limited and local situations.

The development of high coloration in rocks occurs most strikingly in arid regions. This is due to the fact that weathering processes are more intense in hot areas where weather conditions vary and fluctuate rapidly and between wide extremes. Here the processes of oxidation and reduction (redox) are highly developed. Traces of organic matter and other reducing substances are always present in country dust. When moisture is present these agents cause iron-oxide micelles, or invisible crystals or particles, to dissolve or peptize; to become mobile and move toward each other; to meet, cohere, and grow into aggregates large enough to be visible. The process of micro-particles moving, uniting and forming macro-particles is known in physical chemistry as "agglomeration" which is somewhat analogous to the process of "aggregation" in soils. The process might also, aptly, be called "ferrugination."

From what has been said it can be inferred that the color of any particular rock need have little relation to the total iron content of the rock and that no degree of hydration of the iron oxide is necessary to produce wide degrees of coloration. In fact, some light-colored rocks may be fairly high in iron content while, contrariwise, some highly ferruginated ones can be low in iron content. It can be said, in general, that the degree of iron coloration of rocks depends upon the extent to which weathering processes have agglomerated and made visible the iron particles in the rocks.

Some rocks may contain considerable iron and still give no ferruginous indication of it. This is possible because of the presence, in the rocks, of one or more substances which prevents the mobility and/or cohesion of iron micelles or microcrystals. Certain alkalis, such as lithium and sodium, constitute such retarding agents. If agglomeration, or ferrugination, already exists, the introduction of such alkalis does not cause de-agglomeration. This is evident in certain areas in the country where calcareous red soils and deposits of red limestone exist. In the permian Redbed region in southwestern United States such areas are prevalent. In these particular situations the red coloration is due to the fact that the agglomerated red iron "pigments" were present when the deposits were laid down and have not since been altered by the calcareous admixtures.

ARTIFICIAL AGGLOMERATION, OR FERRUGINATION

Perhaps a somewhat clearer idea of the process of agglomeration, or aggregation, or ferrugination, by which rocks and soils are made red-colored, may be had by examining certain phenomena known to ceramists, or to brick and tile workers. For example, most clays, but not all, when burned in a kiln, become red colored. The amount of iron present in the clay does not, necessarily, determine the final color of a tile or brick. Neither does the original color of the clay do this.

When fresh clay is burned in a kiln a concatenation of reactions takes place, as follows: moisture is driven out, including water of crystallization or hydration; organic matter is destroyed and any reduced iron present is oxidized to the ferric form, mainly hematitic; iron molecules become mobile, move about and unite with each other to form, at first, sub-microscopic aggregates. These aggregates then unite to form microscopic aggregates and the process continues

active until the aggregates become large enough to be seen with the naked eye. It is at this time that the clay assumes the red hematite color—brick red. It is possible, however to regulate to various extents the resulting colors of ceramic products. For example, if a certain kind of clay, such as kaolin, is colored pinkish, or reddish by burning and a white or uncolored product is desired, a “de-agglomerating” agent can be added to the clay before burning. This agent can, in some manner, prevent the iron in the clay from becoming mobile and growing into larger, visible-sized particles. Therefore the usual iron-red color does not result. Agents which have this property are mostly alkalinizing, or reducing, in nature. The mechanism of the pronounced reddish coloration of rocks and soils in nature, commonly known as “weathering”, is essentially the same as above described—it just takes much longer to happen.

SOIL COLORATION

Soil coloration, although it involves the essential mechanisms of rock coloration, is more complicated than the latter because of the influence of organic matter. Soil is a product of rock disintegration and is modified chemically and physically by decomposing plants and animals which become admixed with it. The degree of modification depends upon the genetics of the soil, the climate effect, and the amount of organic matter present.

Organic (humic) matter is acidic in reaction and is the precursor of humus and humic acids. These substances contain phenolic groups, including tannins, quinones, etc., which are brownish to reddish in color. These phenolic, or benzene ring, compounds act not only as acid indicators but also as oxidation-reduction (redox) indicators. Thus soil color can change with varying degrees of acidity, or alkalinity, and with varying moisture and aeration conditions. Furthermore, phenolic radicals have the property of uniting with metallic radicals to form a whole gamut of differently colored compounds. Thus the possibilities of colors in soils are infinite in number. More than 4,000 distinct soil types have been officially mapped in the United States and no two types have the same color (Marbut, 1935). In the official classification of the soils of the U. S., the U. S. Department of Agriculture has emphasized the scheme of soil colors in the different states.

For example, the soils of the Northeastern states belong, mainly,

to the Gray Podzolic and the Brown Podzolic Soil Groups. Those of the Southeastern states belong, mainly, to the Red-Yellow Podzolic soils. In the Prairie Region are found the black Chernozem, the Chestnut-Colored, and the Black Waxy soils. West of the Rockies are situated the Inter-Mountain and Desert soils, and the Pacific Coast soils, all of which vary widely in color and other properties. Within the recognized Great Soil Groups there are always smaller, irregularly situated, subgroups which do not conform to the main group in their characteristic color and other properties. This is due to peculiar combinations of soil origins with the local ecological conditions present.

It has already been stated that the color of any iron-colored rock or soil is not necessarily proportional to their total iron contents but is due rather to the degree and extent of agglomeration of their iron particles. Clarke states that where the iron content of a soil is less than five per cent the iron content consists mostly of a thin coat of iron around the soil particles, probably only a few molecules thick (Clarke, 1920). In this case the color could be somewhat proportional to the iron content up to approximately five per cent. MacCarthy found that, in iron-stained sands and clays, the iron content, up to about five per cent, seems to be influenced strongly by the presence in the soils of bases, such as potassium, sodium, etc. (MacCarthy, 1926). Beyond five per cent of iron, however, there seemed to be no correlation of iron color and iron content.

The writer has worked with soils, which had not more than three per cent of total iron, which were as highly iron-colored as were certain other soils which contained five or more times as much iron. The earthy material in the Mesabi Range of Minnesota, containing as much as 65 per cent of iron oxide, is no redder or more ferruginous than are some soils which contain not more than eight or ten per cent of iron, all in the form of ferric oxide. But a great color-difference *potential* between these high and low iron soil materials *can* be present. This may be demonstrated as follows: If small dry samples of each of the high-iron and low-iron soils, of approximately the same color, are placed in mortars and carefully pestled, the color of the high-iron soil will change comparatively little while that of the low-iron soil may be radically changed. In the latter instance the color may be changed from a deep red to a light yellowish ochre color. The change in hue, here, is entirely

a physical one since it involves merely the breakdown of the iron aggregates and their dispersion back into the soil matrix.

The effect which organic matter can have on soil coloration can probably be visualized best by aid of the "soil catena" concept (Bushnell, 1942). The term "soil catena" implies areal associations and gradations of soils in their relation to drainage conditions—ranging from excessively drained to permanently water saturated. The ecology of the soil changes with every change in moisture condition as do also the natures of the involved soil processes. In general, the soils at the drier end of the soil chain will receive less organic matter (the species of plant matters little) and will be more acidic in reaction than those at the wetter end of the chain. The well-drained soils are subject to a predominantly oxidizing environment and thus tend toward a lighter coloration. At the wettest end of the scale, not only will more organic matter be formed but that which is formed tends to be less decomposable than the drier-land organic matter. The term "ektodynamorphic" was coined to involve all soil processes in connection with the wet situation, and the term "endodynamorphic" for the dry situation (Glinka, 1914). Between these limits range extreme variations in soil acidity and soil aeration (redox) conditions. These variations cause great differences in the nature of the soil humus which is formed and it is the humus which governs soil coloration.

Two terms in humus nomenclature have been invented to account for the humus variation, from the dry to the wet conditions, viz., "Mor", and "Mull" (Romell, 1932). These terms applied originally to forest soils but have now become applicable to all soils (Plice, 1945). Mor humus is formed in the better drained situations, lies mostly on the surface of the ground, and ranges in color from light-brownish to deep reddish brown. Mull humus is mostly incorporated with the mineral soil to various depths and ranges in color from light-gray to black. The processes by which these two humus types are formed are widely divergent in nature. Mor humus is formed in an environment which is dominantly oxidizing in nature (Plice, 1945) and its resulting colors are due to color indicators from plant phenolics which are affected by acids and bases (Thomson, 1958), and (Fairbairn, 1958). Quinones constitute the largest group of natural coloring matters. Mull humus is formed in an environment which is dominantly reducing in nature

and its coloration is due to reduced phenolic, or tannic, color—indicating substances. These, due to the fact that much hydrogen and oxygen have been lost in the reduction process in the soil organic matter, take on darker hues because of the relatively large increase in carbon content.

It is quite possible that the process by which mull humus is formed is related to that by which coal is formed and that mor humus formation is similar to lignite formation. Erasmus shows that organic matter which undergoes a "coalification" process during coal formation loses considerable acidity, hydrogen, and oxygen and gains considerable carbon (Erasmus, 1938). The carbon assumes a partial graphitic nature and becomes blackish in color. Further, organic matter which is formed into lignite loses much more carbon and gains more hydrogen and oxygen, relatively, and loses only little in acidity. The color of lignite remains similar to that of the organic matter from which it was formed (Moore, 1940).

In order to get some light on the chemical natures of the two humus forms, mull and mor, combustion analyses were made on the organic fractions of several samples of black prairie (chernozem) (Glinka, 1914) soil from southwestern Minnesota, and of several samples of brown forest soil from central Minnesota. The carbon, hydrogen, and oxygen percentages, respectively, for the mor humus were 30, 7, and 40; and for the mull humus were 47, 5, and 11. The color of the mor humus was reddish brown and that of the mull humus practically the same as that of graphite.

Between the upper and lower limits of ecological situations of the soil catena, mentioned above, great variations exist at all times. The colors of the in-between soils vary with these variations. Perhaps the most difficult to understand of all soil colors is gray, and its variants. In Geology, particularly, it has been mostly assumed that the gray colors of rocks, and of finer-textured rock material, such as glacial clay, are due to the domination in those materials of ferrous, or reduced, iron. In the present work this could not be confirmed. Even the, supposedly, most reliable ferric and ferrous ion indicators, including dipyridyl and ferron, proved to be completely erratic.

In the most difficult of all materials dealt with—glacial clay—it was discerned that the clay contained partially "coalified" organic

matter. When this organic matter was peptized by alternate acid and base treatment, with leaching, it was finally, and completely removed from the mineral matrix. The extracted mineral material was now nearly white in color and highly silicious. The organic matter, when purified and dried, was graphitic in color and had a composition very similar to that of the pure mull humus material. From this and related experiments it is believed that the gray colors of soils are due mostly, if not entirely, to the presence therein of varying amounts of the very stable, partially "carbonized" organic matter. Subsequent study of several coal-measure shales revealed the same results; the presence of small quantities of the stabilized, or "mull-sized" organic matter caused light-gray colored shales, and larger quantities caused darker colored shales. Here again it is impossible to predict from the color of the soil how much organic matter it contains. In Russia there are Steppe soils which are nearly as black as coal and which have an organic matter content of only one per cent (Glinka, 1914). The writer has studied samples of Steppe soils and found that the organic matter therein is appreciably higher in carbon, and lower in hydrogen and oxygen, than that contained in the Chernozem soils of the North Red River valley area, in Minnesota and North and South Dakota. The Steppe organic matter has been "coalified" to the extent that, when extracted and powdered, it looks very much like coal dust. In fact, it contains somewhat more than a trace of "fixed carbon", and fixed carbon is the main feature of coal properties. The exact reason for the coloration of any substance is, of course, its ability to absorb, or reflect, visible light, and this ability is closely related to the electron configurations of the substance which also determine all of its other properties.

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